Draft Version 2

CHEHALIS RIVER BASIN

Stream and Precipitation Gauge Report

Prepared for:
Chehalis River Basin Flood Authority

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ESA Adolfson

EXECUTIVE SUMMARY

The Chehalis River Basin Flood Control Authority (Authority) is interested in providing additional stream and/or precipitation gauges in the basin if additional gauges would improve the accuracy and timeliness of flood forecasting. To determine the need for additional gauges, ESA Adolfson compiled information on existing gauges in the basin and interviewed National Weather Service staff to gather information on flood prediction and recommendations for the gauge network in the basin.

Existing Stream and Precipitation Gauges

The active stream and precipitation gauges in the Chehalis River basin are shown in Figure 1. There are 37 active stream gauges. The United States Geological Survey (USGS) manages 19 gauges; the National Weather Service manages two gauges; the Washington Department of Ecology (Ecology) manages 14 gauges; and Thurston County manages two gauges (see Appendix A). Of these gauges, only the ones managed by the USGS are reported in real time and included in the USGS Flood Watch system. The National Weather Service uses 13 precipitation gauges in the Chehalis basin (see Appendix A).

National Weather Service Flood Forecasting

Flood forecasting for western Washington, including the Chehalis River basin, is done by the Seattle Weather Forecast Office and the Northwest River Forecast Center. Forecasting is based on precipitation predictions and hydrologic models that predict runoff in the basin. The forecasting process is explained in Appendix B.

The National Weather Service uses nine official forecast and warning gauge points in the Chehalis River basin. The stream gauges used for forecast points are located at:

- The Chehalis River near Doty (new in 2008),
- The Chehalis River at Centralia,
- The Centralia River at Grand Mound,
- The Chehalis River at Porter,
- The Newaukum River near Chehalis,
- The Skookumchuck River near Bucoda,
- The Skookumchuck River at Centralia,
- The Satsop River near Satsop, and
- The Wynoochee River.

When forecasting indicates that flooding will occur, the National Weather Service issues a flood warning for the affected river or rivers. When a flood warning is issued, the National Weather Service posts the data on the Advanced Hydrographic Prediction Service page of the internet and communicates with emergency managers.

National Weather Service Recommendations

ESA Adolfson interviewed National Weather Service staff to determine what recommendations they have for improving the precipitation and stream gauge network in the Chehalis River basin. According to the staff interviewed, the existing gauge system is adequate for the overall, regional modeling and predictions for the basin. Staff does not recommend adding forecast or modeling points because of time and staff limitations. Any new points would require removing existing points because the model is saturated. This could be justified if the new points would improve forecasting in areas of the basin that have experienced repeated flooding and do not have precipitation or stream gauge coverage.

Although it considers the overall forecast and modeling system adequate, the National Weather Service acknowledges that additional precipitation or stream gauges could help local forecasting and emergency response. The National Weather Service staff made several recommendations for improving the local stream and precipitation gauge network to improve local forecasting and emergency response, including:

- Install realtime staff gauges on small streams in the basin that experience flooding.
- Install additional precipitation gauges to provide the public with more accurate and timely information. Additional gauges in southern Lewis County would be especially useful.
- Consider developing a local gauge monitoring system such as the ALERT system used in Snohomish County.
- Install SNOTEL stations in upper elevations to provide information on snowpack. Currently there are none in the Chehalis River basin.
- Consider converting some of the existing Ecology stream gauges to telemetry for use by the National Weather Service. Gauge 23G060 on the South Fork of the Chehalis River would be especially useful.

The National Weather Service is interested in continuing to contribute recommendations to the Authority. Staff said they could make better-informed recommendations with more information about specific flood damage areas. National Weather Service staff posed several question to the Authority related to gauging and monitoring (see Conclusions section of the report). ESA Adolfson will coordinate with the Authority to address those issues.

Snohomish County ALERT System

Snohomish County has developed a local flood warning system that uses a combination of USGS gauges and County-operated ALERT system gauges. The County maintains a web site with real-time flood warnings. The warnings are made for four phases of flood and each phase is tied to actual flood events to help the public understand the risk. The report includes cost and personnel estimates for maintaining such a system.

CONTENTS

1.0 INTRODUCTION

The Chehalis River Basin Flood Control Authority (Authority) is interested in providing additional stream and/or precipitation gauges in the basin if the additional gauges would improve the accuracy and timeliness of flood forecasting. There is a perception that the existing stream and precipitation gauges are not adequate to predict flood events and that additional gauges would improve the accuracy of predictions. To determine the need for additional gauges, ESA Adolfson compiled information on existing gauges in the basin and interviewed National Weather Service staff to gather information on flood prediction in the basin and recommendations for additional gauges. This report provides the Authority with a summary of existing gauges in the basin (Appendix A), a discussion of National Weather Service flood forecasting in the basin (Appendix B), and National Weather Service recommendations for gauges. The report also includes a brief summary of the ALERT system used in Snohomish County.

The active stream and precipitation gauges in the Chehalis River basin are shown in Figure 1. There are 37 active stream gauges. The United States Geological Survey (USGS) manages 19 gauges; the National Weather Service manages two gauges; the Washington Department of Ecology (Ecology) manages 14 gauges; and Thurston County manages two gauges (see Appendix A). Of these gauges, only the ones managed by the USGS are reported in real time and included in the USGS Flood Watch system. The National Weather Service uses 13 precipitation gauges in the Chehalis basin (see Appendix A).

2.0 NATIONAL WEATHER SERVICE FLOOD FORECASTING

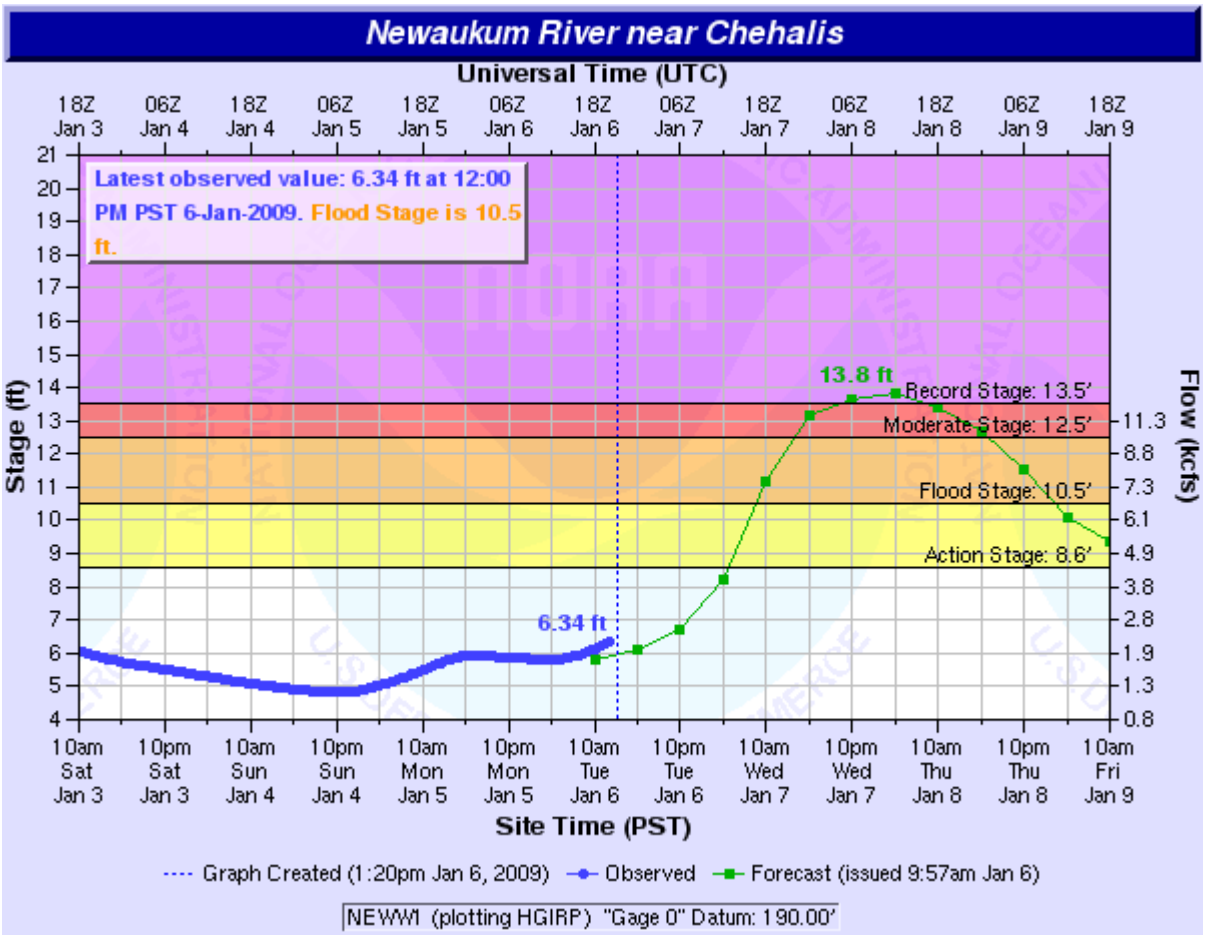
Flood forecasting for western Washington, including the Chehalis River basin, is done by the Seattle Weather Forecast Office and the Northwest River Forecast Center. The Northwest River Forecast Center, located in Portland, Oregon, houses the regional stream gauge monitoring station covering northern California, Oregon, Washington, most of Idaho, and western Montana. The flood forecasting is based on hydrologic models. The process is explained in Appendix B.

The results of the stream and weather models are presented as a weather forecast issued by the Weather Forecast Office in Seattle. Precipitation is forecast in six-hour increments three days in advance. River forecasts are also done on a six-hour basis. During flood events, forecasts are made more frequently, as often as four times per day. There are three main components of a flood forecast:

1. When water levels will rise above flood stage;
2. When water levels will fall below flood stage; and
3. When the main crest or peak will occur.

A flood warning is issued for a specific river and reach of a river at a single gauge (forecasting) point. Flood advisories are posted for larger areas, such as an urban area or small stream, based on the amount of rainfall. The Northwest River Forecast Center collaborates with local weather forecast offices to ground truth the models with local and current conditions. The Northwest River Forecast Center and the Weather Forecast Office post their data on the Advanced Hydrographic Prediction Service page of the internet[1] and communicate with emergency managers during floods and other weather events.

The graphic below is an example of a flood warning hydrograph produced by the National Weather Service for a flood warning. The flood warning, posted on Tuesday, January 6, 2009, predicted major flooding on the Newaukum River for Wednesday night and Thursday. Similar hydrographs were posted for other rivers in the Chehalis River basin.



[1] http://ahps2.wrh.noaa.gov/ahps2/forecasts.php?wfo=sew&view=1,1,1,1,1,1,1,1&toggles=10,7,8,2,9,15,6

3.0 NATIONAL WEATHER SERVICE RECOMMENDATIONS FOR THE CHEHALIS RIVER BASIN

3.1 General Recommendations

It is unlikely that the National Weather Service will add additional forecast points in the Chehalis Basin because the hydrologic model used by the Northwest River Forecast Center is already saturated with forecast points. The National Weather Service currently has no resources to analyze additional forecast points. For example, gauge 12020800 on the South Fork Chehalis River is not included in the forecast for this reason. Essentially, adding one forecast point would mean having to remove a forecast point from another location. The decision whether to add more forecast points would depend on the benefit of the location of the point and the impact it would have on staff time.

In general, when selecting locations for new gauges, the National Weather Service recommends locations that have experienced multiple flood events. The installation of additional precipitation gauges should fill gaps in existing gauge placement and terrain in the basin to provide a representative sample. Gauges equipped with telemetry and placed in upstream areas would increase accuracy. Adding more realtime gauges and upstream gauges would increase timeliness, as long as the river stage and historical data are available for that gauge (which takes five to 10 years to establish).

There are currently no local forecast gauge points in the Chehalis River basin. Local forecast points require both a gauge and realtime data that can be transmitted directly to the National Weather Service. Data from local forecast points can be used to issue a flash flood or river flood warning, but not to make flood forecasts. Local forecast points could be added in areas where flooding is an issue. Ideally, both upstream and downstream locations would be included so that hydrologic patterns could be followed over time, increasing the accuracy of predictions. For each forecast point, data need to be collected and archived for five to 10 years and combined with several independent flood events. This would determine when the gauge data are showing a strong enough correlation with upstream and downstream data to be used by the National Weather Service for making flood forecasts. National Weather Service staff currently has no recommendations for how many or where these gauges should be located.

Realtime staff gauges could be installed throughout the basin in small streams that are expected to flood. National Weather Service staff has no specific recommendations at this time for how many gauges or where they should be located. The realtime gauges would be read during a flood event to convey the water level rise. If it were feasible, automated gauges would be preferable since they report 24 hours a day and transmit via phone or satellite. However, automated gauges are more expensive and could limit the number of gauges potentially installed.

Installing additional rain gauges could be helpful in providing the public with more accurate, timely information. Specifically, more rain gauges would be useful in south Lewis County. Information from any new gauge could be useful in some form, although

the National Weather Service needs a historical basis to utilize the information in its models. In addition, the gauges must be capable of running consistently and under adverse conditions, and they must be consistently maintained. All stream gauge data must be stable and well-calibrated for use in making forecasts. Gauges that do not meet these standards are generally not used by the National Weather Service.

In addition to these general recommendations, National Weather Service staff had the following specific suggestions and recommendations.

3.2 Local Gauge Monitoring Systems

Several places in the United States use local gauge monitoring systems. Local gauge monitoring uses Automated Local Evaluation in Real Time (ALERT) systems. This is a method of using remote sensors to transmit environmental data to a central computer in real time. This standard was developed in the 1970s by the National Weather Service and has been used by the National Weather Service, USGS, Army Corps of Engineers, Bureau of Reclamation, and numerous state and local agencies. In Washington, Snohomish County has a local flood warning system, but few other counties in Washington do (See Section 4).

Rain and stream gauges are the most common type of local gauge system. These systems can provide the same services as a USGS gauge, but the owner is responsible for providing maintenance and analyzing the data. These gauges can be useful if staff is trained in managing the gauges. Cities or counties interested in managing their own gauges can combine ALERT technology and telemetry to tie into National Weather Service data. The results may be issued as a flash flood or river flood warning when an event occurs, but could not be used for regular weather forecasts. ESA Adolfson is continuing to research these options for the Chehalis River basin.

3.3 Converting Existing Gauges

The existing Ecology gauges in the Chehalis River basin could provide useful data for the National Weather Service. Because not all of the existing Ecology gauges transmit realtime data, these would need to be converted for National Weather Service use. In particular, the National Weather Service suggests that gauge 23G060, located on the South Fork Chehalis River near the mouth (RM 0.6), would be useful if converted to telemetry.

There are two Weyerhaeuser precipitation gauges in the Chehalis River basin area. These gauges are not equipped with telemetry; at least one is located within the basin between the Chehalis River mainstem and South Fork. The National Weather Service did not use these gauges during the 2007 flood event because the data were not available. The National Weather Service did review precipitation records for the Weyerhaeuser gauges after the flood. Weyerhaeuser has expressed an interest in converting these to telemetry for use by the National Weather Service. If converted, these two gauges would fill data gaps in the south portion of the basin.

3.4 SNOTEL

SNOTEL (snowpack telemetry) gauges are interspersed throughout the region, but none are located within the Chehalis River basin. These types of gauges are operated by the Natural Resources Conservation Service (NRCS) and record precipitation, temperature, and snowpack. Each system is equipped with a "snow pillow" (rubber pad) that uses the weight of the snowpack to measure how much water is present. This provides quantitative data on snowpack accumulation and depletion as well as precipitation. There are no SNOTEL units between Mt. St. Helens and Mt. Rainier, resulting in a large data gap which can be critical in forecasting impacts to streams. The recommended number is one SNOTEL unit per basin. The National Weather Service recommends three locations for SNOTEL units in the Chehalis River basin area:

1. Blaney Lookout. This location in the far southeast corner of Pacific County in the Willapa Hills is representative of snowpack for the south portion of the basin. This location would provide data for modeling the Chehalis River and other rivers that flow to the south.

2. Cascade foothills east of Bucoda. This site on the east side of Lewis County in the Cowlitz River basin would provide data for modeling the Skookumchuck and Newaukum Rivers, as well as other nearby rivers draining from the Cascades. Because mid-elevation snow is not expected to last all winter, this can be a key component in forecasting rain-on-snow flood events.

3. South slope of the Olympics. The proposed location near the headwaters of the Wynoochee River or Satsop River would provide information on mid-elevation snowpack levels.

Approximate locations for these gauges are shown in Figure 2. Two of the proposed locations are outside the Chehalis River basin, but are close enough to provide valuable data on snowpack in the basin.

The cost of installing a SNOTEL gauge is approximately $30,000, including equipment and labor. In remote sites that cannot be accessed by roads, helicopter installation costs an additional $15,000 to $20,000. Annual maintenance for the sites is approximately $3,000. Land use permitting can raise costs by up to $10,000.

4.0 SNOHOMISH COUNTY FLOOD WARNING SYSTEM

Snohomish County has developed a local flood warning system managed through its Surface Water Management (SWM) Department. The County developed the system in the 1990s in response to repeated flooding. The County wanted to provide more accurate, timely flood forecasting data to Snohomish County residents. At the time, the County considered the cost of additional USGS gauges to be prohibitive and chose to use the ALERT system instead.

The Snohomish County ALERT system currently consists of five USGS real-time gauges and nine flood warning gauges which report in real-time. During flood events, data from the gauges are updated every 15 minutes and posted on line on the SWM Flood Status and River Levels Map[2]. The County reports flood forecasts in four phases with Phase 1 floods being the least severe and Phase 4 floods being the most severe. The flood phase categories are described in the following table.

Flood Phase	What Happens During this Phase?
Phase 1	During Phase 1, actual flooding is rare. County staff put on alert. Preparations are made to open the County's Flood Warning Center.
Phase 2	Minor flooding and some road closures may occur. The County Flood Warning Center opens. Staff begins monitoring river gages and flood conditions around the clock. Gage information is updated hourly on the flood information phone lines. Flood updates are reported to police, schools, fire departments, other agencies, and news media.
Phase 3	Moderate to severe flooding, with numerous road closures and some levee overtopping can be expected. Investigation crews are sent to monitor flood control facilities such as levees. Flood warnings are reported to police, fire departments, schools, other agencies, and news media.
Phase 4	All agencies respond in anticipation of major flooding and widespread damage. Flood warnings are reported to police, fire departments, schools, other agencies, and news media.

To help the public understand the level of flooding, the County ties the flood phases to actual flood events. For example, during a Phase 2 flood on the Snohomish River, a table notes that "Overflow begins at Old Snohomish-Monroe Highway near Snohomish." The web site includes tables that describe actual flooding events for each flood phase, for each river.

The flood forecasting gauges consist of gauges maintained by USGS and by Snohomish County. The County pays approximately 60 percent of the cost to sponsor a USGS gauge and pays an annual fee for USGS to monitor and maintain each gauge. The nine County flood warning gauges are ALERT system staff gauges that are installed and maintained by a County river technician.

[2] http://www.co.snohomish.wa.us/PWApp/SWM/floodwarn/index.html

The ALERT system gauges collect river stage (height), but do not calculate flow. Over time, a rating curve is developed as more data are collected. Each ALERT system gauge costs between $20,000 and $30,000 to install by trained County staff. The county budgets approximately $200,000 annually for installing and maintaining the gauges. Funding comes from three primary sources—the watershed management area fund (surface water fee); river fund; and road funds. Other costs include voice synthesizers to communicate between the data loggers and cell phones, as well as other electronic equipment. The County uses DIADvisor to host the real-time flood warning website.

Snohomish County currently uses 2.5 full time employees to install and maintain the ALERT system staff gauges. This includes one engineer, one river technician, and one part-time employee. For purposes of installing a new ALERT system, recommendations include using 3 to 4 part time employees to install and 2 full time employees to maintain the gauges.

Snohomish County has installed one new staff gauge approximately every other year since the ALERT system began. The County plans to continue expanding the ALERT system. It proposes to add additional gauges along the Pilchuck River and to add existing USGS and Ecology gauges to their real-time flood warning map.

5.0 CONCLUSIONS

Initial recommendations provided by the National Weather Service for the Chehalis River basin are as follows:

1. Install local forecast points in both upstream and downstream areas where flooding has occurred and gauges are lacking upstream of flood-prone areas;

2. Install realtime staff gauges throughout the basin for use during flood events;

3. Install additional precipitation gauges;

4. Consider converting some of the Ecology gauges to telemetry for use by the National Weather Service to fill data gaps, particularly gauge 23G060;

5. Install three SNOTEL units: near Blaney Lookout in the Willapa Hills; in the Cascade foothills east of Bucoda; and along the south slope of the Olympic Mountains.

The National Weather Service staff is interested in contributing additional recommendations throughout the planning process. National Weather Service staff said they could make better-informed recommendations if they were provided with additional information on flood damage locations from the December 2007 flood event. ESA Adolfson will continue to coordinate with them if directed by the Flood Authority.

National Weather Service staff posed several questions for the Authority to consider:

1. Do the counties have staff trained to evaluate the statistics/probabilities or stage heights? These are issued on a weekly basis and 90 days in advance based on flood stage as the probability of exceeded flood stage.

2. Is the Authority interested in adding gauges in locations that already have forecasts or adding new forecast locations where flooding is expected or has occurred?

3. Will the Authority provide the staff to monitor new gauges and analyze the data if local gauges are installed? Counties could contract with an ALERT group, and this could be combined with National Weather Service data, generally saving some money although some services would be lost.

4. Who would provide the funding for converting Ecology gauges to telemetry?

FIGURES

APPENDIX A:
EXISTING PRECIPITATION AND STREAM GAUGES
IN THE CHEHALIS RIVER BASIN

A. EXISTING STREAM AND PRECIPITATION GAUGES

Figure 1 illustrates the location of precipitation and stream gauges in the Chehalis River basin. These gauges are managed by a variety of agencies as indicated in Tables A-1 and A-2. There are 35 active stream gauges in the Chehalis River Basin (Table A-1). The USGS manages 19 gauges; the National Weather Service manages two gauges; and Ecology manages 14 gauges in the basin. Data from all of the gauges managed by the USGS are reported in realtime and included in the USGS Flood Watch system. The National Weather Service reports some data in near realtime at the Newaukum River near Chehalis, the Chehalis River at Centralia, and the Skookumchuck River near Chehalis. All but three of the Ecology gauges are manual staff height gauges and are not appropriate for flood monitoring. Ecology estimates the cost of upgrading the manual staff gauges to near realtime gauges at $10,000 to $20,000 per station with annual operation costs totaling an additional $10,000 to $20,000 per year per station (Brad Hopkins, Ecology, personal communication).

Table A-1. Chehalis River Basin Stream Gauges

Number	Location	River Mile	Drainage Area (sq. mi.)	Date of Record	Managing/Funding Agency	Notes
12020000	Chehalis River near Doty	101.8	113	1939-present	USGS/USGS NSIP	Realtime data
12020800	South Fork Chehalis River near Wildwood	16.2	27	1998-present	USGS/Lewis County Public Works Department*	Seasonal gauge Realtime data
12021800	Chehalis River near Adna	86	340	1998-present	USGS/Lewis County Public Works Department*	Seasonal gauge Elevation/stage only station Realtime data
12024000	South Fork Newaukum River near Onalaska	22.8	42.4	1944-present	USGS/Lewis County Public Works Department*	Seasonal gauge Realtime data
12024400	NF Newaukum River above Bear Creek	7.7	29.6	1998-present	USGS/Lewis County Public Works Department*	Seasonal gauge Realtime data
12025000	Newaukum River near Chehalis	4.1	155	1929-present	USGS/Lewis County Public Works Department*	Realtime data
12025100	Chehalis River at WWTP at Chehalis	74.3	618	2000-present	USGS/Lewis County Public Works Department*	Realtime data Seasonal gauge Elevation/stage only station
12025500	Chehalis River at Centralia	67.5	653	Pre-2000-present	National Weather Service	Realtime data

Number	Location	River Mile	Drainage Area (sq. mi.)	Date of Record	Managing/Funding Agency	Notes
12025700	Skookumchuck River near Vail	28.8	40.0	1967-present	USGS/Skookumchuck Dam, LLC.	Realtime data
12026150	Skookumchuck River at Bloody Run Creek near Centralia	20.7	65.9	1969-present	USGS/Skookumchuck Dam, LLC.	Realtime data
12026400	Skookumchuck River near Bucoda	6.4	112	1967-present	USGS/Skookumchuck Dam, LLC. and Thurston County*	Realtime data
12026600	Skookumchuck River at Centralia	2.5	170	Pre-2000-present	National Weather Service	Realtime data
12027500	Chehalis River near Grand Mound	59.9	895	1928-present	USGS/Ecology	Realtime data
12031000	Chehalis River at Porter	33.3	1,294	1952-present	USGS/Ecology	Realtime data
12035000	Satsop River near Satsop	2.3	299	1929-present	USGS/Ecology and USGS NSIP	Realtime data
12035002	Chehalis River near Satsop	18	1,760	1979-present	USGS/Energy Northwest	Realtime data Stage velocity readings Affected by tides and debris
12035100	Chehalis River near Montesano	13.2	1,780	2001-present	USGS/USGS NSIP	Realtime data Affected by tides
12035400	Wynoochee River near Grisdale	51.3	41.3	1965-present	USGS/City of Tacoma, Tacoma Public Utilities	Realtime data
12036000	Wynoochee River above Save Creek near Aberdeen	40.6	71.4	1925-present	USGS/City of Tacoma, Tacoma Public Utilities	Realtime data
12037400	Wynoochee River above Black Creek near Montesano	5.9	155.2	1956-present	USGS/City of Tacoma, Tacoma Public Utilities	Realtime data
12039005	Humptulips River below Highway 101 bridge near Humptulips	22.9	132	1933-present (most information 2002-present)	USGS/Grays Harbor County	Realtime data

Number	Location	River Mile	Drainage Area (sq. mi.)	Date of Record	Managing/Funding Agency	Notes
22R050	North Fork Satsop River at the Mouth	0.3	Not available	2005 to present	Ecology	Manual staff height
22D110	Wishkah River near Nisson	15.3	Not available	2005-present	Ecology	Telemetry
22K070	Bingham Creek at Hatchery	0.1	Not available	2000-present	Ecology	Telemetry
22L070	Johns River at Western	5.5	Not available	2005-present	Ecology	Manual staff height
22M070	Newskah Creek below Falls	4.1	Not available	2005-present	Ecology	Manual staff height
22N070	Middle Fork Hoquiam River near New London	Not avail-able	Not available	2005-present	Ecology	Manual staff height
22P080	East Fork Hoquiam River near Nisson	10.0	Not available	2005-present	Ecology	Manual staff height
22Q060	East Fork Wishkah River near mouth	0.9	Not available	2005-present	Ecology	Manual staff height
22S050	Decker Creek at mouth	0.1	Not available	2005-present	Ecology	Manual staff height
23A130	Chehalis River at Claquato	77.7	Not available	2005-present	Ecology	Manual staff height
23A160	Chehalis River at Dryad	96.9	Not available	1996-present	Ecology	Manual staff height
23E060	Black River at Highway 12	2.0	Not available	2005-present	Ecology	Telemetry
23G060	South Fork Chehalis River near mouth	0.6	Not available	2005-present	Ecology	Manual staff height
23H 070	Cedar Creek at Highway 12	1.3	Not available	2005-present	Ecology	Manual staff height
None	Black River at 128th Avenue Littlerock	?	Not available	1992-1999, 2006-present	Thurston County	
None	Scatter Creek at James Road	?	Not available	1995-1998, 2007-present	Thurston County	

* The Authority has authorized funds for upgrades or repairs to these gauges.

The National Weather Service uses 13 precipitation gauges in the Chehalis River basin. These are listed in Table A-2. Two of the gauges are Remote Automated Weather System (RAWS) observation stations, which are part of the National Interagency Fire Center system. Two of the gauges are Limited Automatic Remote Collectors (LARC). One of the gauges is an Automated Local Evaluation in Real Time (ALERT) station. Two of the gauges—Francis and the Olympia Airport—are located outside the Chehalis River basin, but are close enough to provide useful forecast information. In addition, there are six other stations listed at the bottom of the table which are not included in the National Weather Service system. Private entities may also maintain precipitation gauges in the basin, but information on those is not readily available.

Table A-2. Precipitation Gauges in the Chehalis River Basin

Gauge Name/Location	Managing Agency	Notes
Huckleberry Ridge	RAWS	Does not operate during the winter at this time
Chehalis	RAWS	
Chehalis-Centralia Airport	National Weather Service	
Francis	LARC National Weather Service	Near the Chehalis River basin
Boisfort Peak	ALERT	
South Fork Chehalis River near Wildwood	USGS	
Cinebar	LARC National Weather Service	
South Fork Newaukum River near Onalaska	USGS	
North Fork Newaukum River near Forest	USGS	
Olympia Airport	National Weather Service	Near the Chehalis River basin
Wynoochee Lake		
Elk Meadows		
Wishkah Headworks	Corps of Engineers	
Citizen Weather Observer station Napavine[1]	APRS/CWOP[2]	
Citizen Weather Observer station Centralia[1]	APRS/CWOP[2]	
Hydrologic Remote Sensing Center Centralia[1]	USGS	At the Centralia stream gauge 12025500
WDFW Skookumchuck Dam Hatchery[1]	Thurston County	Under construction
Black River at 128th Ave, Littlerock[1]	Thurston County	At the Black River stream gauge (1989-present)
Scatter Creek at James Road[1]	Thurston County	At the Scatter Creek stream gauge (2006-present)

[1] Not used by the National Weather Service for forecasting
[2] Automated Position Reporting System/Citizen Weather Observer Position

APPENDIX B:
NATIONAL WEATHER SERVICE FLOOD FORECASTING

B. NATIONAL WEATHER SERVICE FLOOD FORECASTING

B.1 Forecasting Models

The Seattle Weather Forecast Office and the Northwest River Forecast Center collaborate to issue flood forecasts for western Washington. The Northwest River Forecast Center in Portland, Oregon, houses the regional stream gauge monitoring station covering northern California, Oregon, Washington, most of Idaho, and western Montana.

Forecasts are made using hydrologic models. The Weather Forecast Office runs weather (precipitation) models and the Northwest River Forecast Center runs stream models; together, these produce a weather forecast. Flood predictions are made using available hydrologic information about stream systems that contribute to runoff. This includes local, urban areas where small streams are monitored, as well as large river systems.

The national headquarters of the National Weather Service provides a set of hydrologic models to the Seattle office on a daily basis. These 13 models are known as the National Centers for Environmental Prediction models, and they describe precipitation, temperature, open water (ocean), hurricane, and other forecast conditions. The National Centers for Environmental Prediction models vary in resolution (12 km to 90 km) and are run multiple times per day. In addition, the Seattle Weather Forecast Office receives modeling output from the University of Washington Department of Atmospheric Sciences' MM5 model. The University of Washington model describes precipitation and temperature at a higher resolution than the National Centers for Environmental Prediction models (4 km scale). The combined output from the National Centers for Environmental Prediction models and the University of Washington model is used to forecast weather conditions.

The Northwest River Forecast Center covers over 360 forecast points in the region, which includes the Columbia and Snake River basins as well as the area west of the Cascades. The Weather Forecast Office and the Northwest River Forecast Center use a separate set of hydrologic models to describe stream conditions, called the National Weather Service River Forecast System. This is a "lumped basin model" that divides an area into sub-basins and then lumps the data into one basin, producing a single value. This model relies on three key components—future forecasts, historic precipitation, and temperature data, all of which are used to calculate runoff. The National Weather Service River Forecast System takes a representative average of all rainfall within a river basin. This averaged value takes into account variations in topography, soil moisture retention, snow accumulation and depletion, and other factors.

There are four main components of the National Weather Service River Forecast System: (1) soil moisture accounting model; (2) Snow 17 model; (3) unit hydrograph model; and (4) routing. The soil moisture accounting model is a conceptual one that describes the process of liquid rainfall or snowmelt as it falls from the clouds and flows into the rivers or is stored in the soil. The Snow 17 model describes solar radiation, temperature, and snowpack. These two models address water that is already on the ground. The unit

hydrograph model describes the amount of runoff that will flow into the rivers and how the rivers will respond. This model accounts for variations in the shape of the river basin, soil types in the basin, and topographic variation. Routing is carried out from one gauge to the next, upstream to downstream, and includes major streams and tributaries as well as local runoff. Routing accounts for how far and how long it takes water to get from one forecast point to another. Each forecast area includes all areas upstream along a routing area.

Data from the National Centers for Environmental Prediction models run in Seattle are shared with the Portland-based Northwest River Forecast Center office. These data are used to run the National Weather Service River Forecast System models. The resulting data from the stream and weather models are presented to the public as a weather forecast by the Seattle office.

Precipitation is forecast in six-hour increments three days in advance. River forecasts are also done on a six-hour basis. River forecasters look at the first 10 days of a forecast showing water levels in a river system and use this information to make flood warnings at specific gauge points.

There are three main components of a flood forecast:

1. When water levels will rise above flood stage;
2. When water levels will fall below flood stage; and
3. When the main crest or peak will occur.

Flood forecasts are made within a 12-hour window and flood outlook forecasts are made two to three days ahead. A flood warning is issued for a specific river and reach of a river at a single gauge (forecasting) point. Flood advisories are posted for larger areas based on the amount of rainfall, such as an urban area or small stream. The Northwest River Forecast Center collaborates with local weather forecast offices (e.g., Seattle) for local and current conditions to ground truth the models. The Northwest River Forecast Center and the Seattle office post their data on the internet and communicate with emergency managers during floods and other weather events.

B.2 Gauges Used for National Weather Service Forecasting

The National Weather Service receives data from a variety of sources. There are currently nine official USGS National Weather Service river forecast and warning points in the Chehalis River basin, which are shown in Table B-1.

Table B-1. Official Forecast and Warning Points in the Chehalis River Basin

Number	Location	River Mile	Drainage Area (sq. mi.)	Date of Record	Managing/Funding Agency	Notes
12020000	Chehalis River near Doty	101.8	113	1939-present	USGS/USGS National Streamflow Information Program	Realtime data
12025000	Newaukum River near Chehalis	4.1	155	1929-present	USGS/Lewis County Public Works Department	Realtime data
12025500	Chehalis River at Centralia	67.5	653	Pre-2000-present	National Weather Service	Realtime data
12026400	Skookumchuck River near Bucoda	6.4	112	1967-present	USGS/Skookumchuck Dam, LLC., and Thurston County	Realtime data
12026600	Skookumchuck River at Centralia	2.5	170	Pre-2000-present	National Weather Service	Realtime data
12027500	Chehalis River near Grand Mound	59.9	895	1928-present	USGS/Ecology	Realtime data
12031000	Chehalis River at Porter	33.3	1,294	1952-present	USGS/Ecology	Realtime data
12035000	Satsop River near Satsop	2.3	299	1929-present	USGS/Ecology and USGS National Streamflow Information Program	Realtime data
12037400	Wynoochee River above Black Creek near Montesano	5.9	155.2	1956-present	USGS/City of Tacoma, Tacoma Public Utilities	Realtime data

One additional gauge, located at the Wynoochee reservoir, records weather data and provides forecasts as well. Reservoir information is also collected at this site.

The National Weather Service uses 13 precipitation gauges in and near the Chehalis River Basin. These are listed in Table A-2. All gauges are used in the precipitation analysis, but only the Francis and Wishkah points are used specifically as forecast points.

There are additional stream and precipitation gauges located in the basin that are not used by the National Weather Service for various reasons. Some gauges are not equipped with telemetry and therefore cannot transmit data directly. The National Weather Service does not currently use the Ecology gauges because it does not know how the Ecology gauges are calibrated, what model schemes are used, or what reference points are used. In addition, the National Weather Service does not always have the resources to review the model for a particular gauge.

APPENDIX C:
NATIONAL WEATHER SERVICE STAFF CONTACT INFORMATION

C. NATIONAL WEATHER SERVICE CONTACTS

J. Brent Bower, Hydrologic Program Manager/Hydrometeorologist, Seattle Weather Forecast Office

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
Seattle Weather Forecast Office
7600 Sandpoint Way NE
Seattle, Washington 98115-0070
Telephone: 206-526-6095 x 228
E-mail: brent.bower@noaa.gov

Kevin Berghoff, Hydrologist, Northwest River Forecast Center

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
Northwest River Forecast Center (NWRFC)
5241 NE 122nd Avenue
Portland, Oregon 97230-1089
Telephone: 503-326-7401
E-mail: kevin.berghoff@noaa.gov

Harold Opitz, Hydrologist in Charge (HIC), Northwest River Forecast Center

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service
Northwest River Forecast Center (NWRFC)
5241 NE 122nd Avenue
Portland, Oregon 97230-1089
Telephone: 503-326-7401 x322

Andy Bryant, Sr. Service Hydrologist, NOAA/NWS Weather Forecast Office

NOAA/NWS Weather Forecast Office
5241 NE 122nd Ave
Portland, OR 97230-1089
Telephone: 503-326-2340 x228
Fax: 503-326-2598
E-mail: andy.bryant@noaa.gov
http://www.wrh.noaa.gov/portland